UDC: 550.36

Zhuk M.S., Tsalko P.B., Zui V.I.

HEAT FLOW WITHIN LOCAL INTERSYNCLINAL STRUCTURES OF THE TORTOISE-SHELL TYPE

Institute of Geological Sciences, NAS of Belarus, Minsk, Belarus, zui@igs.ac.by

Abstract

Results of regional investigations of terrestrial temperature field within intersynclinal local structures of so-called "tortoise-shell type" are discussed. Such geological structures were distinguished within the central part of the Pripyat Trough. Heat flow density estimates are fulfilled for a number of drillholes. The influence of hydrogeologic conditions, salt tectonics, mineralogical composition of rocks in the platform cover are discussed.

Introduction

Positive salt-free structures, developed by salt tectonics in above-the-salt deposits of the Pripyat Trough, exist along with salt domes [1]. Such raises were distinguished within the Vasilevichi, Bazhenov, Bereznyaki, Zaozernaya, Kalinkovichi and other structures. They are detected most clearly by seismic methods by several reflecting horizons and usually correspond to lower and middle carboniferous limestone, the Permian and Triassic clay and sandstone rocks.

Such structures represent an interest in the relation to the construction of artificial underground gas storages (UGG) within the territory of Belarus [2, 3]. The Mytvian suite of the Moscovian Stage of the Middle Carboniferous and the Korenevichi Suite of the Induan Stage (the Lower Triassic). They represent the consistent geological strike thickness of sandy deposits and have the value to construct the UGG within the Vasilevichi, Bazhenov and other brachyanticlines. The Mytvian sediments have smaller in area extent as compared to the Korenevichi deposits. They also absent in dome parts of salt swells. Clays of the Gulevichian and Dneprovian suites of the Moscovian Stage overlap them, as well as dense red bed argillites of the Dudichi Suite, the Upper Permian. In this aspect it is important to study the detailed structure of the terrestrial temperature field parameters both within the Korenevichi and the Mytvian suites as well as within the overlying rocks. The same concerns the field structure of the whole sedimentary cover of tortoise-shell type raises.

Until the recent time, the geothermal field features of such structures were not studied. We determined heat flow density (HFD) values for 18 drillholes within the central part of the Pripyat Trough. These calculations were based on separate determination of interval values of geothermal gradients and heat conductivity measurements of rock samples (Table 1). Several interval flow values, determined for each of holes, increase the HFD resolution. More than 600 rock samples of different mineralogical composition selected from drill cores of boreholes drilled within the Pripyat Trough, were used for individual heat conductivity measurements. These laboratory measurements were fulfilled in different years. All available data were analyzed to receive averaged calculated values for studied individual layers, comprising the platform cover. Heat flow density data were determined for a number of depth intervals for each of studied boreholes to be able to reveal the tendency of their vertical variation.

A wide spectrum of heat conductivity coefficients was observed for sediments of the Pripyat Trough. The terrigenous and terrigenous-clayey deposits of Jurassic, Permian, Triassic, Carboniferous and above-the-salt Devonian sediments (clay, sandstone and siltstone rocks) have low heat conductivity coefficients, ranged from 1.5 to 2.5 W/m·K. Malm rocks of above-the-salt Devonian sediments exhibited the lowest heat conductivity values 1.3 – 2.0 W/m·K with the mean value of 1.5 W/m·K among carbonates, represented here by dolomites, malms, chalks. Some scatter is observed in heat conductivity coefficients (1.9 – 3.2 W/m·K) at the mean of 2.4 W/m·K for dolomites of above-the-salt Devonian thickness. High heat conductivity ranged from 2.8 to 5.6 at the average of 3.6 W/m·K is typical for dolomites of the inter-salt Devonian deposits. Heat conductivity varies for carbonate rocks. It depends mainly on the amount of sand-clayey component, the moisture content and the rock porosity. They noticeably influence the average heat conductivity of sedimentary rocks. The existence of crystalline structure in dolomites brings them closely to crystalline rocks in their heat conductivity. It ranged from 3.1 to 4.8 W/m·K for measured samples of the Devonian anhydrite at the mean value of 4.1 W/m·K. Layers, comprised of the Devonian rock salt, showed the highest heat conductivity 3.8 – 7.9 W/m·K (the average value was 5.6 W/m·K) depending on the amount of clayey, terrigenous-clayey and carbonate admixtures. The temperature correction was applied for rock salt conductivity [4] when calculating heat flow density values.

A number of holes were drilled in salt domes and the vicinity. The information on their geologic structure was completed by geophysical investigations. Temperature measurements were fulfilled in most of boreholes here. The available heat conductivity data gave a possibility to calculate heat flow density values for individual depth intervals. The error bar of calculations was estimated to be in the range of 10 to 25 %. Salt tectonics [1, 5] sufficiently influences the observed heat flow. Calculated interval HFD values lie in the range 4 to 103 mW/m^2 (see the Table 1). Low heat flow values are typical for depth intervals, corresponding the upper and middle hydrogeological stages with active water exchange, in particular the Devonian above-the salt, Carboniferous, Permian, Triassic, Jurassic, Cretaceous and Quaternary deposits.

Low heat flow density values (4 to 50 mW/m^2) observed within the uppermost part of the sedimentary sequence till the depth of upper salt Devonian deposits for boreholes located within the next structures: Vasilevichi (2-k, 3-k and 4-k holes), Novinskaya (holes 2-r and 3-r), Bazhenov (holes 1-r, 4-r), as well as the Yurovichi 1-r, Zaozernaya 3-r boreholes is resulting from the the underground water filtration cooling this part of the sedimentary cover. According to the hydrogeological zonality, it corresponds to the upper and middle stage with noticeable water filtration velocities. The most active water movement takes place within the lower part of the Cretaceous (quartz-glauconite sands and Cenomanian sandstones), Jurassic (Oxfordian sandy-carbonate formation), as well as the Triassic (Induan sandy-clayish sediments). It corresponds to the thick water- and brine-bearing complex [6]. Pressure water within it frequently results in concaved shape of thermograms.

Considerable heat flow density variations within the geological structure of the tortoise-shell type result from its redistribution Fig.1. Several factors cause this; one of them is already mentioned above pronounced groundwater filtration within permeable sediments, the second factor results from developed salt tectonics of the area under consideration. Contrast of heat conductivity of rock salt, comprising salt domes and swells, and surrounding terrigenous rocks results in a deflection of heat flow vectors of its vertical direction, especially in the vicinities of salt domes. Maximal vertical components of heat flow vectors correspond to upper parts of salt domes. The shape and extent of such local anomalies depend on the geometry of easch of salt domes and salt diapers. We observe for the Smaglovskaya 2-R borehole, for instance, HFD corresponds to 88 mW/m^2 for the interval 1100-1200 meters and to 82 mW/m^2 for the interval 2000-2100 meters. Within the interval 800-900 m, corresponding to the cap rock of the dome observed HFD is 77 mW/m^2 and it drops to 72 mW/m^2 within the interval of 1900-2000 m for the Nikulinskaya 6-R drillhole. Heat flow in general increases with the depth until it reaches 72 mW/m^2 within the interval 800-1600 meters in the Zolotukhinskaya 2-R hole.

We studied a number of other studied sites (see Table 1). Similar situation exists in heat flow density distribution in salt domes and salt diapers developed within the Ostashkovichi, Pervomaisk, Rechitsa and other geological structures [7, 8] of the Pripyat Trough. For instance, the heat flow density maximum of 76-80 mW/m^2 was observed at the interval of 760-1052 meters in the salt dome of the Rechitsa structure. It reaches 107 mW/m^2 in the interval of 450-530 m in the well 17 of the Rechitsa structure and even 120 mW/m^2 in the interval 500-535 m (cap rock) of the well 128 drilled within the same Rechitsa oil field, it decreases to normal values outside the Rechitsa salt dome: 69-80 mW/m^2 (well 93), 45-92 mW/m^2 (well 4) and 65-87 mW/m^2 (well 12).

Contrast pattern of heat flow density distribution exists within above-the dome deposits of the Zolotikha structute, in particular within Cretaceous, Jurassic, Triassic, Permian, Carboniferous and the above-the-salt Devonian sediments the observed heat flow ranges from 27 to 100 mW/m^2 (hole 3-R), from 46 to 103 mW/m^2 (hole 2-R). Within deposits overlying the Smaglovskaya Brachianticlinal it ranges from 13 to 92 mW/m^2 (see Fig.1). As it was mentioned above, the main factors influencing this scatter are pronounced groundwater filtration within loose sediments of the upper hydrogeological stage existing in above-the salt part of the platform cover, by heat redistribution caused by salt tectonics, as well as effects of ground surface paleotemperature variations. The salt tectonics weakens the cap rocks terrigenous deposits integrity, overlying the salt dome body, increases its decompaction and permeability for underground fluids, resulting in origination of convective heat flow component. In result, the higher observed geothermal gradient here is observed, as well as corresponding increased interval values of heat flow density within such cracked zones above these salt domes.

The existence of the decompaction zone and its hydrodynamic connection to the zone of active water exchange within the Meso-Cenozoic deposits was confirmed by investigations conducted within the South-Kazanskaya Syncline of the Pripyat Trough [9]. It was confirmed for the first time the conditions and the mechanism of the development of the “tortoise-shell type” uplifts, complicating the structure of above-the salt sediments of the Trough based on reliable seismic records. The existences of small blocks due to the rootless discordance unconformity downthrows are the distinguishing features of such structures. Actually, it relates to all similar structures of the Pripyat Trough such as the Vasilevichi, Bazhenov, Zaozernaya and others). It is possible to consider that low heat flow values 21-38 mW/m^2 in the domes of the Bazhenov inter-dome brachianticline is caused mainly by the downward water filtration along paths of decompaction of the above-the-salt Devonian, Carboniferous, Permian and Triassic rocks complex. Increased heat flow 42-68 mW/m^2 within above-the-salt Devonian deposits in the Smaglovskaya 1 hole is the result of heat supply from the lower geothermal complex by upward filtrating fluids. The HFD convective component here could be comparable with the conductive one.

Conclusion

Anomalies of high heat flow density within areas of salt domes and salt diapers development have contrast lateral heat flow density variations. The highest HFD values correspond to the uppermost parts of domes and cap rocks, formed by them. High heat conductivity of rock salt relatively to adjoining terrigenous sediments result in “focusing” and redistribution of the heat transferred from below and from the crystalline basement into the platform cover. Salt tectonics is the main factor resulting in high HFD values observed within cap rocks, developed above the domes, where the heat inflow along weakened paths plays sufficient role in this process. Upwelling of warmed up fluids along these paths results in existence here the convective heat transfer component.

References

1. Tectonics of Belarus, 1976. (R.G. Garetsky Ed.). Nauka i Tekhnika, Minsk, 200 pp *(in Russian).*
2. Monkevich K.N., Tsalko P.B., Tolstosheev V.I., Makarenko V.M., 1977. On perspectives of construction of underground gas storages within the Pripyat Trough. *Doklady AN Belarusi, V.41, No.5, pp.105-109 (in Russian).*
3. Garetsky R.G., Monkevich K.N., Tolstosheev V.I., Tsalko P.B., 1998. Structures of the Pripyat Trough as potential underground gas storages. *Geologiya Nefti i Gaza., No.11, pp.2-7 (in Russian).*
4. Kozel V.P., Parkhomov M.D., 1981. Experimental investigations of thermophysical properties of rocks as a function of temperature. In: Elovicheva Ya.K., Shkuratov V.I., Shpakov O.N. (Editors). Materials of geological investigations of the territory of Byelorussia. Nauka i Tekhnika, Minsk, pp. 41-45 *(in Russian).*
5. Konishchev, V.S., 1975. Salt tectonics of the Pripyat Trough. Nauka i Tekhnika, Minsk, 150 pp. *(in Russian).*
6. Kudelsky, A.V., 1987. Hydrogeology of the western part of the Sarmatia-Turanian lineament. Nauka i Tekhnika, Minsk, 111 pp. *(in Russian).*
7. Tsybulya, L.A., Levashkevich, V.G., 1990. Heat flow within the Pripyat Trough and reasons of its heterogeneity. *Geologicheskii Zhurnal, No.11, pp.19-26 (in Russian).*
8. Zhuk, M.S., Makarenko, V.M., Tsalko, P.B., 1993. Geothermal conditions of the southern part of the Pripyat Trough. *Doklady AN BSSRi, V.37, No.4, pp.195-113 (in Russian).*
9. Kudryavets, I.D., Levkovets, V.P., 1998. Tectonics and oil- and gas-bearing capabilities of the South-Kazanskaya Symcline of the Pripyat Trough. *Lithosphere, No.9, pp.97-105 (in Russian).*

Table 1

Vertical distribution of observed heat flow density observed in some of boreholes drilled within the central part of the Pripyat Trough.

Таблица 1

Вертикальное распределение наблюдаемой плотности теплового потока в отдельных скважинах центральной части Припятского прогиба.

Nos.	Hole name and its number	Coordinates		Geol. Age	Depth interval, m	Temp. Grad. mK/m	HC, W/m·K	HFD, mW/m^2	
		Lat.	Long.					Interval	Undis-turbed
1	2	3	4	5	6	7	8	9	10
1	Vasilevichi 2-K			K_2t	101-176	13.3	2.0	27	
				J_3ox + J_2cl	230-270	13.2	1.7	22	23
				J_2bt + T_1 ol-ld??	275-345	11.4	2.0	23	
				T_1in	500-570	10.1	1.8	18	
2	Vasilevichi 3-K			K_2t	120-160	15.0	2.0	30	
				J_3ox	210-280	10.7	1.8	19	
				J_2bt + T_1ol-ld?	300-480	14.2	2.0	28	25
				T_1in	560-620	10.0	1.8	18	
3	Vasilevichi 3-K			K_2t + J_3ox	140-300	8.3	2.2	17	
				T_1ol-ld?	330-430	15.5	2.2	34	
				T_1in	430-460	8.3	1.8	15	23
				T_1in	460-520	13.3	1.8	23	
				T_1in + C_2mt	520-600	8.1	2.3	19	
4	Vasilevichi 12-K			K_2t	155-180	20.0	2.0	40	
				J_3ox	205-240	17.8	1.8	31	23
				J_2 + T_1mg	270-430	7.9	2.2	17	
5	Novinskaya 2-R			K_2t	120-160	15.0	2.0	30	
				J_3ox + J_3cl	240-280	35.0	1.9	66	
				T_1mz	360-500	22.8	2.2	50	
				T_1in	500-540	17.5	1.8	32	
				T_1in	600-675	15.3	1.8	19	
				T_1in	675-750	25.3	1.6	40	66
				C_2nd	780-1020	16.0	2.2	35	
				D_3pl	1020-1290	26.4	1.8	53	
				D_3lb	1975-3430	13.4	4.8	64	
				D_3rd-	3430-3875	28.5	3.3	64	

				el					
				D_3lv	3875-4300	17.3	3.7	65	
				D_3vr-ln	4600-4700	26.6	2.6	66	
6	Novinskaya 3-R			T_1ol-ld	400-620	17.2	2.0	54	
				T_1in	620-900	2.1	1.8	4	
				T_1in	900-960	10.0	1.8	18	
				T_1in	960-1000	20.0	2.0	40	
				P_2l + D_3pl	1000-1120	20.8	2.0	42	
				D_3pl	1200-1750	15.5	2.2	34	48
				D_3lb	1750-1950	7.5	6.4	48	
				D_3lb	1950-2200	10.6	6.2	56	
				D_3lb	2800-3200	13.0	4.8	62	
				D_3lb	3200-3560	7.5	6.5	49	
				D_3rd-el	3560-3810	14.0	2.5	35	
				D_3lv	3810-4120	7.5	6.4	48	
7	Zolotukhin-skaya 2-R			K_2t	100-125	51.6	2.0	103	
				J	150-275	21.6	2.1	46	
				T	275-550	29.5	2.2	65	
				P_2	550-750	20.1	2.3	46	72
				D_3pl	750-800	27.0	1.8	49	
				D_3lb	800-1600	12.7	5.7	72	
8	Zolotukhin-skaya 3-R			K_2t	80-160	50.0	2.0	100	
				J	240-320	30.0	2.1	60	
				T	320-420	17.0	2.2	37	
				P_2	680-690	20.0	2.3	46	
				C	700-800	25.0	2.0	50	
				C	820-920	15.0	1.8	27	
				C	1000-1227	21.0	1.7	36	
				D_3pl	1227-1700	24.3	1.8	44	
				D_3lb	1850-1950	12.0	4.3	52	60
				D_3lb	200-2300	15.0	4.0	60	
				D_3lb	2500-2605	20.0	3.3	66	
				D_3rd-el	2700-2880	23.0	2.5	58	
				D_3lv	2900-3000	28.0	2.3	64	
				D_3lv	3300-3710	10.0	6.0	60	
9	Zaozernaya 3-R			K_2t	103-155	25.0	2.0	50	
				J_{2-3} - T	171-224	22.6	2.1	47	
				P_2	320-368	20.8	2.3	48	
				C_2m	368-445	10.4	1.8	19	35
				C_2ol	579-619	20.0	1.6	32	
				C_1	642-965	6.2	1.8	11	
				C_1	965-1117	17.1	2.2	38	
				D_3pl	1117-1463	16.5	2.0	33	

10	Yurovichs-kaya 1-R			T	383-470	21.3	2.2	47	72
				C_2m	710-900	12.6	1.7	21	
				C_2b	900-1180	15.2	1.8	27	
				C_1	1180-1255	10.7	1.9	20	
				C_1	1255-1310	22.7	1.6	36	
				D_3pl	1310-1900	16.7	1.8	30	
				D_3pl	1990-2138	36.1	1.5	54	
				D_3lb	2150-2250	15.0	3.3	50	
				D_3lb	2250-2310	11.7	4.0	47	
				D_3lb	2455-2532	7.8	6.2	48	
				D_3lb	2532-2745	13.4	3.7	50	
				D_3lb	2905-3210	12.0	4.6	55	
				D_3lb	3210-3530	20.1	3.1	62	
				D_3lb	3530-3792	11.6	5.7	66	
11	Bazhenov-skaya 1-R			K	100-200	25.0	2.0	50	41
				T_1kr	400-500	12.0	1.8	22	
				C_1t	900-1000	16.0	1.8	29	
				D_3pl	1000-1100	12.0	1.8	22	
				D_3pl	1100-1200	17.0	1.7	29	
				D_3pl	1200-1400	11.5	1.8	21	
				D_3pl	1400-1500	20.0	1.5	30	
				D_3pl	1500-1600	27.0	1.5	41	
12	Bazhenov-skaya 4-R			T_1kr	400-500	10.0	1.8	18	70
				P_2 + C_2m	500-700	16.0	2.4	38	
				C_1t	800-1100	18.0	1.8	32	
				D_3pl (dn)	1100-1200	16.0	1.8	29	
				D_3pl (dn)	1200-1300	21.0	1.7	36	
				D_3pl (dn)	1300-1400	16.0	1.8	29	
				D_3pl (dn)	1400-1700	24.0	1.5	36	
				D_3lb (??)	1700-1900	14.5	5.6	81	
				D_3lb (??)	1900-2100	16.0	5.2	83	
				D_3lb (??)	2100-2200	11.0	5.6	62	
				D_3lb (??)	2200-2600	13.5	5.5	74	
				D_3lb (??)	2600-2900	19.0	4.1	81	
				D_3lb (??)	2900-3000	13.0	5.6	73	
				D_3rd-el	3000-3300	21.0	3.2	67	

				D_3lv	3300-3700	12.5	5.6	70	
				D_3ev	3700-3800	14.0	2.7	38	
				D_3vr + sn	3800-3900	20.0	2.5	50	
13	Nikulins-kaya 1-R			P	800-900	9.0	2.7	24	
				C + D D_3pl	900-1200	14.0	1.8	25	
				D_3lb(??)	1500-1800	12.0	5.6	67	
				D_3lb(??)	1800-1900	19.0	4.0	76	
				D_3lb(??)	1900-2500	7.0	6.3	44	51
				D_3rd-el	2500-2900	12.5	3.2	40	
				D_3lv	2900-3500	8.0	6.3	50	
				D_3ev	3600-3700	13.0	3.6	47	
				D_3pr-nr + PR_2	3800-3900	21.0	2.5	52	
14	Nikulins-kaya 4-R			T + P	500-800	7.5	1.8	13	
				P + C	800-1000	12.0	2.4	29	
				C + D_3pl	1100-1200	24.0	1.8	43	
				D_3lb (??)	1200-1500	11.3	5.6	63	
				D_3lb (??)	2100-2300	8.0	6.3	50	
				D_3lb (??)	2300-2400	12.0	5.6	67	55
				D_3rd	2600-2800	23.7	2.5	59	
				D_3lv	2900-3500	10.0	5.8	58	
				D_3ev + nr	3500-3600	15.0	3.5	52	
				D_3ps-nn	3600-3900	11.5	3.2	37	
15	Nikulins-kaya 4-R			D_3lb	800-900	14.0	5.5	77	
				D_3lb	900-1900	11.0	5.6	62	
				D_3lb	1900-2000	13.0	5.5	72	
				D_3lb	2000-2200	10.5	5.7	60	72
				D_3lb	2200-2300	12.5	5.5	69	
				D_3lb	2300-2400	19.5	3.6	70	
				D_3rd-el	2400-2600	30.0	2.5	75	
16	Nikulins-kaya 7-R			K_2t	100-200	20.0	2.0	40	
				T	400-500	25.0	1.8	45	
				T	700-800	19.0	1.8	34	

				T_1kr	800-1000	12.5	2.3	29	
				C + D_3pl	1000-1100	19.0	1.7	32	
				C + D_3pl	1100-1200	23.0	1.8	41	
				C + D_3pl	1200-1300	20.0	1.8	36	
				D_3lb	1300-1500	12.0	5.6	67	
				D_3lb	1500-1800	15.0	5.2	78	
				D_3lb	1800-2100	12.0	5.6	67	
				D_3lb	2100-2200	14.0	5.3	74	
				D_3lb	2200-2300	20.0	3.8	76	63
				D_3lb	2300-2500	8.0	6.3	50	
				D_3lb	2500-2700	13.5	4.0	54	
				D_3rd-el	2700-2800	22.0	2.5	57	
				D_3rd-el	2900-3000	27.0	2.2	59	
				D_3lv	3000-3100	18.0	3.6	65	
				D_3lv	3100-3400	11.0	5.6	62	
				D_3ev	3500-3600	19.0	2.7	51	
				D_3vr + sn	3600-3700	17.0	3.0	51	
17	Smaglovs-kaya 1-R			P_2 + C_1m	1000-1300	21.0	2.0	42	
				D_3pl	1300-1700	28.0	1.8	50	
				D_3lb	1700-1800	16.0	5.2	83	
				D_3lb	1800-2000	10.0	5.6	56	
				D_3lb	2000-2200	13.0	5.2	68	
				D_3lb	2200-2300	20.0	3.8	76	
				D_3lb	2300-2400	16.0	5.2	83	
				D_3lb	2400-2500	25	3.3	82	
				D_3lb	2500-2600	14.0	5.6	74	63
				D_3lb	2600-2800	8.5	6.3	54	
				D_3rd-el	2800-2900	17.0	2.6	44	
				D_3rd-el	2900-3000	24.0	2.5	60	
				D_3rd-el	3000-3100	20.0	2.6	52	
				D_3lv	3200-3300	17.0	3.8	65	
				D_3lv	3300-3400	11.0	5.6	62	
				D_3lv	3400-3500	7.0	5.8	41	
				D_3ev + sm	3500-3700	13.5	2.7	36	
18	Smaglovs-kaya 1-R			K_2t	100-200	46.0	2.0	92	
				J	200-300	18.0	2.2	40	
				T_1kr	600-900	7.5	1.8	13	
				D_3pl	900-1000	13.0	1.8	23	
				D_3lb	1000-1100	9.0	6.3	57	

				D_3lb	1100-1200	17.0	5.2	88	
				D_3lb	1200-1700	13.2	5.4	71	
				D_3lb	1700-2000	15.0	5.2	78	
				D_3lb	2000-2100	19.0	4.3	82	
				D_3lv	2200-2300	18.0	4.0	72	
				D_3lb	2300-2900	22.0	3.5	77	
				D_3lb	2900-3600	15.0	5.2	78	
				D_3ev + sm	3800-4220	26.0	2.7	70	

Подрисуночные подписи

(Надо добавить)

Fig.1. ?????
Рис.1. ?????

Подрисуночная подпись должна включать номер рисунка и располагаться под рисунком с выравниванием по центру. Формат подрисуночной подписи: Times New Roman, 10 пт, п/ж.